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ABSTRACT

A theoretical model relating problem identification to problem solving is presented. The main purpose of the study is to increase understanding of decision making among Air Force educators. The problem-solving process is defined as the generation and evaluation of alternatives that will accomplish what is needed and the reidentification of what is needed based on the experience of generating and evaluating the alternatives. An analysis of problem solving is presented which extends the Gestalt approach. The paper is divided into seven chapters: (1) the Deweyan tradition, the Gestalt model, and the information processing model; (2) definition; (3) deductive inference, inductive inference, and analogical inference; (4) long-term memory; (5) management processes; (6) problem identification as well as generation and evaluation of alternatives; and (7) the theory of reidentification as it creates a better understanding of how problem-solving abilities develop through performance rather than description or definition. References are included in the document. (Author/DB)

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GENERAL DESCRIPTION OF HUMAN PROBLEM SOLVING

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Current theories of problem solving have no explanatory account of the processes of problem identification. Gestalt approaches to problem solving did not have this limitation; a problem was seen as undergoing continual reidentification throughout the problem solving process. An analysis of problem solving is presented which extends the Gestalt work. Problem solving is defined as two simultaneous processes: the generation and evaluation of alternatives that will accomplish what is needed, and the reidentification of what is needed on the basis of the experience of generating and evaluating the alternatives. This approach integrates inferential activities, long-term memory, and the management of a limited capacity operational memory into a general account of problem solving.

PREFACE

This report represents a contribution to the research program of Project 1710, Training for Advanced Air Force Systems, Ross L. Morgan, Project Scientist; Task 171003, Training Implications of New Military Technology, Bertram W. Cream, Task Scientist. It is an expanded version of a paper to be presented at the 1976 American Psychological Association Convention, Washington, D.C., entitled "Inferential Processes and Problem Identification."

The contributions of the work of the Gestalt psychologists Duncker and Wertheimer, and the philosophical tradition embodied in the work of Harré, Hesse, and Dreyfus are easily ignored in the area of applied psychology. In generating the present theoretical model, their ideas have been combined and developed to provide a description of problem solving and decision making that may have value for the understanding and training of many diverse tasks and specialties within the Air Force.

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GENERAL DESCRIPTION OF HUMAN PROBLEM SOLVING

I. PREVIOUS APPROACHES

We shall begin our development of a theory of problem solving with an account of three approaches to problem solving. Our intention is not to summarize or review this work, but to determine the general strengths and weaknesses of each approach in order to determine how to incorporate the various strengths and avoid the weaknesses.

The Deweyan Tradition

Training-oriented theories of problem solving have attempted to identify the major steps in problem solving. Professionals working in this tradition try to determine the stage in which a problem solver is having difficulty, and suggest activities that will allow him to overcome this difficulty. The seminal work in this tradition is Dewey, 1910, Chap. 7. Dewey listed five phases of problem solving: (a) recognition that there is difficulty, (b) defining the problem, (c) generating hypotheses as to the solution of the problem, (d) elaborating these hypotheses and inferring their properties, and (e) testing the hypotheses. This stage model has appeared in various forms in the areas of education (Gagné, 1966), mental health (D'Zurilla & Goldfried, 1971) and business management (Kepner & Tregoe, 1965). No one has questioned this analysis, even though no evidence has been gathered for it. Dewey was careful to claim that he was not proposing an invariant sequence of stages. The phases are all reasonable; they are certainly necessary features of our problem solving behavior.

The training-oriented tradition has been successful in developing some techniques to help problem solvers accomplish the phases described by Dewey. D'Zurilla and Goldfried (1971) have discussed the importance of problem identification, and have presented techniques for training students and patients to apply problem solving procedures. Techniques such as brainstorming (Osborn, 1953), have been developed for increasing creativity in hypothesis generation.

The individuals working in the training-oriented tradition were not concerned with providing a more complete account of the psychological processes that make up each phase. This has severely limited the explanatory power and potential for growth of their accounts. The phases are merely named, reflecting our intuition that different processes must be at work in each phase, but nothing is said about what these processes are. The only characteristic of memory they presuppose is that it is tenaciously retentive. Their methods are essentially variations on "jarring associations loose." A satisfactory theory of problem solving will have to specify the psychological processes involved.

The Gestalt Model

The Gestalt approach (e.g., Duncker, 1945; Köhler, 1927; and Wertheimer, 1959), is to examine the specific processes that underlie problem solving. This close attention to psychological processes is precisely what is omitted from the training-oriented tradition. There are similarities in the Gestalt accounts of perception and problem solving. In each case something is presented whose identification depends upon its being organized into a coherent structured whole by processes in the organism. These internal processes may produce alternative organizations, as in the Necker cube. They distribute prominence to different parts in a figure-ground effect that in problem solving is called "insight into the structure of a problem."

The Gestalt approach emphasizes the structure of a problem and the reorganization of how a problem is seen that is frequently necessary to produce a solution. In order to study this reorganizational process, Gestalt researchers traditionally employed complex situations that required some analysis to derive an accurate identification of the problem. More clearly than the training-oriented work, the Gestalt research has shown the central importance of the problem definition processes.

Duncker has also shown how the failure of a hypothesis is a vehicle for reformulation. The failed hypothesis serves as a comparison case and a retrieval cue. A solver can ask how it is like and unlike a genuine solution. Specifying the differences adds to the identification of the problem by listing things to be avoided. Specifying the similarities is a partial description of the solution, a part of the ultimately complete description.

A specific example is the problem of how to use X-rays to kill an internal tumor without injuring nondiseased tissue. A problem solver may suggest using a low intensity beam that would become stronger when passing through the tumor. This is physically impossible. There is no way to modulate radiation that has already been emitted. However, this failure may encourage the problem solver to reformulate the problem from "How can I kill only diseased tissue with the X-ray?" to "How can I make the radiation stronger at the site of tumor?" He can ask "Why did I think this would work?", a version of "How is this like a good solution?" This helps make explicit, and therefore usable, what may have been an unconscious reformulation. It may suggest a method of using several beams to focus radiation on the tumor.

According to Duncker, the problem solver is continually learning more about the parameters and properties of the solution by the process of generating and evaluating hypothesized solutions. The evaluation of alternative hypotheses is a medium for reformulating the problem.

Because it has very few parameters of individual variation, the Gestalt model says very little about how to improve problem solving, except for admonitions to look for the structure of the problem, and to avoid functional fixedness. Duncker has suggested some methods of hypothesis generation (e.g., similarity, perceptual connections between elements), but these do not allow explanation of difficulties or suggestions for improvement.

The Information Processing Model

The information processing approach aims at an analysis of the internal processes that are important for solving problems. This analysis takes the form of a sequence of steps that will lead to a solution. Often the goal is to write a computer program which will perform those steps. The paragon work in this field is Newell and Simon (1972).

This approach has introduced a variety of heuristic techniques for generating alternatives, reducing the number of alternatives to be searched, detecting and eliminating difficulties. A major contribution is the detailed analysis of the processes of generating and evaluating alternatives (the 3rd and 4th of Dewey's phases). Our criticism of information processing theories is based on their simplifying assumption that the individual processes of generating and evaluating alternatives can be studied in isolation. The identification of the problem is a basic part of problem solving.[1] Theories which omit problem definition activities must be incomplete and potentially distorted accounts of the entire process since problem identification often interacts with the search for solutions. This limitation is the cost of the advance made from Gestalt to information processing models. The greater specificity was gained at the expense of restricting the range and concern of the model. Information processing accounts begin with a problem already specified. They are based on a distinction between well-defined and ill-defined problems. A well-defined problem is one for which there are ready criteria for potential solutions, such as with chess, logic, engineering, and mathematics. With ill-defined problems, there is no immediate way to recognize solutions. Examples would include problems in historical analysis, psychotherapy, labor-management disputes. Newell and Simon have restricted their concern to well-defined problems. One of our concerns is to explain how an ill-defined problem is understood and becomes well-defined. Our account of problem solving emphasizes those aspects that have been de-emphasized by Newell and Simon.

An examination of the use of feedback in information processing models illustrates how a cybernetic approach will omit problem reformulation processes. In information processing models, the possible outputs of an operation must be listed in advance. Progression to the next step is determined by which predefined result the operation produces. For example, an operation can be: [Is A = B? If yes, go to . . .; If no, go to . . .] The failure of an hypothesis in this scheme will lead to the examination of the next generated hypothesis. But the failure of an hypothesis in human problem solving, as we have seen, can lead to important new discoveries about the problem. The subjects in Duncker's protocols often analyzed their failures in order to reorganize their approach to a problem.[2]

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[1] This point was recognized by Miller, Galanter and Pribram (1960, p. 172) early in the application of cybernetics to psychology.

[2] The tendency to substitute simulation for explanation often biases information processing accounts toward using primitive terms (and postulating processes) which are too closely modelled upon computer components. Some instances have been discussed by Dreyfus (1972): people notice things much more quickly than information processing accounts would expect, the human nervous system allows context effects not possible in computer memory systems, computer operations are sequential and atomistic, whereas psychological activities are continuous and interactive.

Problem identification is closely related to the issue of motivation. People experience needs, typically a combination of many needs at any one time. Problem solving is a recognition of and response to these needs. Solutions are recognized primarily by their effect on these needs. Human problem solving takes place in a real-world context, which provides a source of external evaluation. If this is all omitted from an account of problem solving, then the means of providing validation will be artificial and the range of problems that can be modelled will be reduced. Many of these points are argued at length by Dreyfus (1972).

Our assessment of the limitations in the information processing approach provides the basis for our own approach, concerned with ill-defined problems and their identification by the problem solver.

II. DEFINITION

The first task of a theory of problem solving is to define the domain of the theory. This is not a trivial undertaking. There are a variety of available definitions. Previous theorists have selected the definition most consistent with their theory. Thus (Davis, 1973, p. 12) working in the training-oriented tradition, defined a problem as a "stimulus situation for which an organism does not have a ready response." This is consistent with his interest in developing creativity techniques for increasing the likelihood of finding a ready response. Unfortunately, his definition suggests that someone who blinks readily to all stimuli can have no problems. No criterion of appropriateness is built into the definition.

Information processing definitions take the problem as already given. Reitman (1965, p. 126) says: "a system has a problem when it has or has been given a description of something but does not yet have anything that satisfies the description." Newell and Simon (1972, p. 72) define a problem as occurring when "a person . . . wants something and does not know immediately what series of actions he can perform to get it." In both definitions, problem solving only begins after the needs have been well-specified.

We claim that problem solving consists of two interacting processes: the ongoing identification of needs, and the search for procedures to satisfy these needs. The needs constitute criteria for the adequacy of the solution; i.e., a solution should bring about the satisfaction of the needs. But these criteria for the solution change as the needs are reidentified in the process of discovering a procedure to satisfy them. The identification of the needs is already a partial description of the procedure, a description of its final state. Problem solving is a process of filling out that description of the procedure, both the final state and the intermediate steps, until the procedure becomes followable and will result in satisfaction of the needs. It is not a trivial point that needs must enter into an account of the problem. The needs, an objective situation, stay constant (or else the entire problem changes); it is their psychological representation that changes.

At the beginning of problem solving, the needs are poorly understood. This makes it difficult to find a procedure that will reduce the needs. Attempts to discover such a procedure allow the needs to become more clearly understood. This in turn makes it easier to describe the necessary properties of a satisfactory procedure. When the description of the procedure is so complete that it can be followed, it constitutes the solution.

For most human problems, the needs are a complex state of affairs, and the representation of these needs is continually changing. The reidentification of the problem involves the same processes that were active in the initial problem identification. The continual reidentification or reformulation of the problem constitutes progress in problem solving. Alternative procedures are generated and their consequences worked out. This process may demonstrate that certain criteria are unnecessary, or that additional criteria are needed, or that some criteria can be specified more exactly. This reidentification continues until the solution criteria can be satisfied by a procedure that has been generated.

Among the psychologically active needs are the personal needs of the solver. For example, if a student in a physics class is asked to solve the X-ray problem, he may suggest making the beam of radiation stronger as it hits the site of the tumor. As this is physically impossible, the suggestion could expose him to class ridicule. He may realize that he needs to appear competent to his peers more than he needs to solve the assigned problem. He, therefore, begins generating procedures that involve particle interactions and the utilization of antimatter. These may not be the best solutions to the X-ray problem, but they satisfy the student's needs more successfully.

We view the area of needs and motivation neutrally. Our definition of problem solving recognizes a wide variety of needs. For example: cellular dehydration is frequently identified as a need for water. It is a problem if it leads to a search for procedures resulting in the delivery of drinkable liquid. Yet, if we are at a party when we are thirsty, we do not snatch the nearest drink if it is resting in someone's hand. We need to maintain cordial relations. In problem solving terms, this reduces to a solution criterion that excludes procedures that will offend people. As we understand problem solving, we may also create a framework for a better understanding of motivation.

The problem solving process that we have defined is dependent on three major cognitive factors: (a) the rules of inference that humans apply to modify and increase their knowledge; (b) a long-term memory system, which stores the beliefs and procedures that must be modified by rules of inference; and (c) a means of managing the operations performed. A theory of problem solving makes assumptions about these three factors. These assumptions will be discussed in the next three sections.

III. RULES OF INFERENCE

A general theory of problem solving must include an account of human inferential activities. These may range from formal derivation of the consequences of certain premises to the use of prior experience to estimate the effectiveness of a series of actions. These are processes that take a person systematically from one cognitive state to another without the input of perceptual information. These processes are necessary for the identification of problems and for the generation and evaluation of solutions to problems.

We think that these processes can be described by a formal inferential system, but this does not mean that they can be described by an existing system; i.e., any standard textbook logic or the probability calculus. These formal systems are useful and legitimate, but they have not in general been designed as descriptive systems. The Piagetian system of formal operations (Inhelder & Piaget, 1958) was designed to be descriptive, but it omits many of the characteristics we feel to be necessary. We do not intend to propose a formal characterization of inference in this section, but we shall present some of the major properties a descriptively adequate logic must have. Our discussion will concentrate on three types of inferential processes: deductive, inductive, and analogical.[3]

Deductive Inference

Deductive processes allow the problem solver to derive consequences, such as what to expect when a procedure is implemented. An important set of guides for inference are the formal systems, logics, algebras, computer programs. Various psychological questions arise about the ability of people to apply formal rules and to see the relevance of formal rules. This has been one domain of the psychology of reasoning (e.g., Wason, 1968). This must be distinguished from the psychology of natural inference (the ways that people naturally reason). Although the study of how people follow formal rules raises important questions, they are only relevant to problem solving for certain very sophisticated problems. Unfortunately it is often assumed that some particular formal system is descriptive of natural inference. This assumption is unwarranted.

Models of natural inference should include certain features of belief because the inferences are transitions from beliefs to new beliefs (rather than truths to new truths).

Beliefs vary in strength. A belief may be held very strongly or with a great deal of suspicion. A formal logic that models this must be a many-valued logic, with a range of variation wider than true and false. Introductions to the variety of many-valued logics have been written by Ackermann (1967) and by Rescher (1969). Sanford (1975) provides a brief though technical review of the problems in this area and also presents a non-truth-functional infinitely-valued logic that avoids some of these problems. A likely model for degrees of belief will be infinitely-valued and probably not truth-functional.

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[3] Peirce (1934-5) called the formal equivalents of these deductive, inductive and abductive. Hesse (1966) and Harré (1970) have suggested that analogy is the basis for abduction. We accept this and will therefore use the term "analogical inference."

Beliefs also vary in degree of clarity. We may be able to state our beliefs very clearly or they may be so vague as to prevent any kind of symbolic representation. Machina (1972) has argued that representation of natural language requires "vague predicates" which demand at least a 3-valued logic. There are also formal models of fuzzy sets (Zadeh, 1965). Goguen (1968-9) has studied the logic of these sets. Among his conclusions is that the product of slightly unreliable deductions can be very unreliable. This suggests the potential fruitfulness of such models as explanations of error.

Inductive Inference

The conventional model for inferences about degrees of belief has been the probability calculus. It is a many-valued logic. It has been used as a model of inductive inference only. Unfortunately, it too has been taken without question as the model for natural inference. Edwards (1968) has reviewed explanations of why human performance should deviate from the probability calculus: misaggregation of information, misperception of information, and denial of the purported deviation by explaining it as an artifact. Cohen (1970) has criticized the descriptive adequacy of the probability calculus, and has developed a different calculus which he claims is more realistic.

It should be noted that in a many-valued logic, inductive inferences can be incorporated into the deductive system. We are suggesting that a single, many-valued logic can be a model for both deductive and inductive inference, but there is a theoretical problem to find a descriptively adequate logic for natural inferences. With a new wave of interest in many-valued logics on the part of logicians, we shall soon have more to choose from.

Analogical Inference

Analogical inference is extremely important for a description of human problem solving, but has received little attention from psychologists. We shall use the term "analogy" to refer to a familiar state of affairs which is used to understand or discover how to proceed in a new state of affairs. Thus an analogy can be a previous experience, a story or slogan.

We claim that there are two major processes of analogical inference. The first process classifies a problem. If my car won't start because the starter motor will not turn over, then if I identify this as an *electrical* problem, a set of procedures for testing circuits and components becomes relevant. In the second process, hypotheses are generated by a perceived similarity. My present problem is like one I experienced two years ago, and I can remember how I handled it then. There are also combinations of these two ways. A classification can suggest a directly relevant familiar situation. Alternately, the comparison between a new situation and one that is perceived as similar may allow the problem solver to discover general properties.

An illustration of analogical inference is provided by the way people understand and predict the actions of others. One major strategy is classification. If we decide someone is obsessive-compulsive, we can understand some of his past behavior, and predict some of his actions. A second strategy is the use of perceived similarities. On first meeting someone, we may note that in some ways, he reminds us of one of our uncles, and in another way he is like a friend from graduate school. This provides a potential for developing an idiosyncratic personality theory based on a set of familiar exemplars which serve as analogies.

The use of analogies provides the problem solver with a means of identifying a problem, of suggesting procedures that may be solutions, and of anticipating the effects of these procedures. Analogical inference provides the problem solver with a basis for planning. An analogy may allow the problem solver to formulate an abstract plan,[4] or it may itself serve as a concrete vehicle for directing his problem solving activities.

[4] Newell and Simon (1972) have made good use of a planning function based on abstraction. However, their model of abstraction requires a preidentification of problem features as essential or inessential. For humans, this categorization would be accomplished by the analogical inference processes.

IV. LONG-TERM MEMORY

In the discussion of rules of inference, two major issues emerged. The first was the importance of describing inferential processes for beliefs that vary in strength and clarity. The second was the role of analogical inference as a source of problem identification and procedure generation. Our discussion of long-term memory will focus on the storage and retrieval necessary for both of these characteristics of inference.

Beliefs are often unclear and uncertain. The representation of these qualities in memory could include a numerical tag for clarity and for degree of confidence. It is more likely that long-term memory is not individuated into items, but is an analogue representation of some kind (Attneave, 1974). Degree of strength and clarity would be inherent properties of the trace rather than additional content.

Analogical inference requires that the problem solver be able to retrieve an analogy which is superficially unlike the problem. It is not clear that such retrieval can be explained in terms of systematic search through an associative hierarchy, from stronger to weaker associative strengths. A more promising model is that of Rumelhart and Abrahamson (1973) which proposes a memory structure like a multi-dimensional Euclidean space. New relationships can cut across old classifications. Even this, however, is too simple a model. Some of the dimensions of variation will be quantitative, some merely ordinal and some categorical. Consider how we can employ our understanding of radar operation to explain a bat's use of echolocation. A radar device uses electrical impulses and is made of metal, the bat uses auditory information and is organic, yet we are able to utilize the similarity. Likeness can be even more complex and subtle. The ability to map a large number of objects into two classes (such as yin and yang) with any consistency at all and to generate images ("...eloquent blood spoke in her cheeks...") are indications of the subtlety of memory structure. Some likeness can be found between almost any two objects or situations: How is a raven like a writing desk? They both have legs, are chemically organic, are found in England. This ability to find similarities is the basis for hypothesis generation.

Analogical inference is not in the form of rules that can be followed because it is dependent upon the structure of its data base. These inferences are a quasiperceptual retrieval process, a form of recognition. The problem situation is recognized as being *like* something else. Tulving and Thomson (1973) and Watkins (1974) have suggested that recognition involves a match with memory information. In our situation, the match with memory is not perfect, it is a match with an analogue. It is not a particular item or label that must be retrieved, but any item *sufficiently like* the problem to suggest a solution. The criterion is relative to the needs. Our analysis resembles that model of recognition-recall in that the analogues are retrieved more readily as more dimensions of the problem are specified. Retrieval thus becomes more likely as problem identification proceeds. Our account is neutral with respect to many other features of the retrieval process (e.g., parallel or serial search).

It is obvious that not every experience can be useful as an analogy. An experience must be sufficiently understood and organized so that it can be retrieved when relevant, and so it can provide useful direction for the new problem. The research of Reed, Ernst, and Banerji (1974) represents an important beginning in the analysis of conditions of analogical utilization.

V. MANAGEMENT PROCESSES

One important limit on inference processes is the amount of information that can be brought to bear in a particular inference. Limitations on available information may reduce the scope of the inference, or prevent its derivation. We will use the concept of operational memory (Posner, 1967) to describe the limited memory "space" available for working out inferential operations.[5] As this "space" becomes larger, inferences can become more powerful. Distinctions can be drawn that might otherwise be missed. Pascual-Leone (1970) has suggested that developmental changes in operational memory are major

[5] This is distinct from limitations in the amount of new material that can be permanently acquired at one time. We are also distinguishing operational memory from attentional limitations, such as only being able to attend to one thing at a time. Our concern with operational memory is for the amount of information that can be integrated into the one ongoing activity.

determinants of intellectual development. Klein (1976) has discussed the importance of operational memory for reading performance. In this section, our concern is with the management processes available for working within the limitations of operational memory capacity.

The effective management of operational memory presupposes a self-model. The problem solver must store in long-term memory a set of beliefs about his own capacities including the properties of his own operational memory. He must be able to recognize when task demands will exceed his limitations. Prediction of the amount of space a specific operation will take in operational memory requires both an anticipation of the task demands and a prediction of the space in operational memory available for the task demands. An example of human reaction to capacity limitations has been presented by deGroot (1966). Chess players know that if they try to work out the implications of too many different moves, they will become confused. Therefore they select only a few moves for thorough analysis. This illustrates an important criterion for management processes: a limited number of alternatives can be generated and evaluated before the confusion produced offsets the information gained. Skilled problem solvers can anticipate and avoid such confusion.

Effective management processes require the ability to determine the fruitfulness of alternatives. This allows the problem solver to ignore alternatives that are unlikely to be successful. Newell and Simon (1972) have noted individual differences in attention to trivial issues as a source of differences in effectiveness of problem solving. This determination of fruitfulness would frequently be based on the analogy that directs the problem solving.

It is also possible to overcome capacity limitations by reducing the operational memory space needed to represent information. Chunking (Miller, 1956; Simon, 1974) is one example of this—storing several items as one unit. Another example would be the use of an abstract term instead of several concrete terms. Weitzenfeld (1974) has made several distinctions here. The development of a concept involves the chunking of beliefs so that they can be applied as a unit. "Labelling" refers to developing an internal code reference that allows easy internal manipulation of the information. The use of symbols allows external manipulation of the information: storing it on paper, communicating it. Labelling and use of symbols can free the available operational memory space, and therefore allow the problem solver to include more information in deriving inferences.

VI. THE PROBLEM SOLVING PROCESS

The last three sections have been primarily structural. Some of the major components of our theory of problem solving were described: rules of inference, long-term memory and management processes. This section uses the structural account to describe the functioning of a problem solver. There are three subsections: problem identification, generation of alternatives, and evaluation of alternatives. These are not sequential stages. Each process interacts with the other two. The identification of the problem determines the alternatives that will be generated as well as the criteria used to evaluate these alternatives. In fact, the way the problem is understood *is* the set of criteria used to evaluate the alternatives. Similarly, the properties of the problem that are inferred during the evaluation process are the basis of problem reidentification.

Problem Identification

The identification of a problem is the recognition that certain needs exist and must be acted upon. For a procedure to be selected as a solution, it must promise to satisfy those needs. However, the identification of the problem is not simply the compiling of a list of needs to be satisfied. The problem solver has to find a wholistic or perspicuous representation of the constellation of needs. This is frequently accomplished by the selection of an appropriate analogy. As the limits of the analogy are explored, a newer analogy may come to be seen, which is a Gestalt shift in the problem identification.

An individual may fail to identify a problem. The need for magnesium salts does not typically get translated into a solution criterion, so people lack a means of directed problem solving to restore magnesium salt balance. When an individual does represent a need, he may do so as a discomfort or complaint, and not as a set of solution criteria. There are individual differences in the representation of need states as problems. Factors such as previous successes, availability of procedures and analogous

situations, and penalties for inadequate performance, all determine an individual's criterion for formulating a need state as a set of solution criteria. D'Zurilla and Goldfried (1971) have suggested that individuals can be taught to use cues such as frustration to initiate problem identification procedures. Maladaptive behaviors can serve as cues that the problem has been misidentified.

Misidentification of a problem occurs frequently since needs are complex, and their interaction is complex. The effects of misidentification can be illustrated by a study reported by Bruner and Potter (1964). An unfocussed stimulus is flashed on a screen, the focus is gradually improved, and the subject is asked to identify the stimulus. When the focus is still poor, and the subject makes an error such as seeing an animal as a piece of furniture, it will take him longer to correctly identify the stimulus. The initial misidentification blocks or postpones attempts to reidentify.

For ill-defined problems, there are often several adequate ways to identify a problem. Any identification is valid that produces a procedure that alleviates the need. Misidentification is marked by a persistence of needs after procedures are implemented. Much work in clinical psychology is directed at allowing the patient to reidentify his problem, to the point where it allows a solution. For example, a person may fear dentists, and avoid their offices. If the problem is identified as inappropriate fear, procedures will be generated for reducing the fear, such as relaxation techniques. But it may be that as a child, the patient was reassured by a dentist that all was going well; shortly thereafter, the dentist struck a nerve. Procedures for promoting trust are therefore required.

Some features of problems can be inferred from the properties already discovered. Often, new information is needed. The example of avoidance of dentists in the previous paragraph illustrates how new data (the way the fear was acquired) allow the inference that reformulates the problem. Techniques for obtaining new information frequently include finding the cause of the problem.

An adequate identification of a problem includes auxiliary solution properties, such as environmental characteristics and personal needs. We will discuss these in order. There are usually features of the environment that must be taken into account. The successful anticipation of these environment-related solution properties requires some familiarity with the environment in which the procedure is to be implemented. For example, an architect is asked to design the layout for the floor of a factory. An implicit problem, however, is to economize on building material. A trained architect will be aware of this. He will place the ladies' restroom near the men's restroom, to conserve plumbing components. It may require more ingenuity to discover that discriminatory hiring patterns have created a situation in which the jobs filled by women are very far from the jobs filled by men, and consequently, far from the ladies' restroom. Anticipation of this feature of the environment adds an additional solution criterion: that the women have easy access to their restroom. It is unlikely that an ideal solution will be found that can satisfy all of these criteria. However, the identification of the criteria is necessary for the architect to make reasonable choices.

The problem solver also brings with him general personal needs which are included as solution criteria. The problem solver may need to have others view him as an authority figure as he solves problems. Or, he may wish to find solutions that allow him to avoid responsibility for them. As the number of solution criteria increases, the likelihood of finding a solution that will satisfy them decreases. It even becomes harder to generate alternatives. When the inclusion of personal needs as solution criteria frequently renders problem solving attempts inadequate, we may label the individual as neurotic.

Generation of Alternatives

The discovery of procedures that can satisfy the solution criteria appears to occur in three different ways: The procedure can be located directly in long-term memory, the procedure can be derived through rules of inference, or, as a last resort, there are combinatory techniques for discovery.

The simplest way to produce a procedure that will satisfy the solution criteria is to retrieve a procedure already known. Any complete theory of problem solving must include a theory of recall, and of the factors that facilitate and inhibit it. Alternately, procedures may be generated by analogical inference. The problem solver may retrieve a previous situation which, because of its similarity to his present situation, can suggest procedures and generally guide his behavior.

Where no existing procedure can be retrieved or suggested through analogical inference, one must be constructed. Combination processes vary a set of existing procedures along a set of relevant dimensions.

Different fields of enquiry have different specific permutation processes, varying in the degree of generality. Polya (1957), for example, has produced a checklist of combination procedures for mathematics. Applied creativity techniques (Davis, 1973) frequently consist of checklists that can be generally used, for example: make it larger, smaller, break it up, fold it, reverse it.

When generation techniques fail to produce an acceptable procedure, there is a technique for unblocking the generation process: delete some of the solution criteria and begin generating again. This type of deletion is essentially the same process as analogical classification. It also characterizes brainstorming. Newell and Simon (1972) give an example of how unblocking can work. It is difficult to generate words that have 3 G's and a Z. Therefore, find words with 3 G's and see if any of them have the letter Z. Words with 3 G's can be most easily generated by using the "ing" form of verbs. This strategy generates "egging," and "begging," but also "agglutinizing," "aggrandizing," and "zigging."

Evaluation of Alternatives

Evaluation consists of matching the solution criteria to the properties and inferred consequences of each alternative procedure. The goal of the evaluation process is to select the procedures that can best satisfy the solution criteria. However, the solution criteria change as the problem is reidentified, since the problem is psychologically represented as a set of solution criteria. Thus, a major output of the evaluation process is the discovery of new solution criterion, and the abandonment of old criteria.

The application of inferential processes to procedures that fail may determine properties that are necessary for acceptable solutions. Concurrently, certain solution criteria may be found to be unnecessary. Analysis of failures may also allow the problem solver to discover errors in inferences. Individual differences in reactions to failures can have strong effects on problem solving. Instead of using failures as opportunities for problem reidentification, individuals may react with frustration, or may attempt to avoid failures. This latter case not only weakens the reidentification process, but may discourage the use of problem solving procedures.

Besides evaluating the alternative procedures, the problem solver will have to select a procedure to implement. Often, either several acceptable procedures are found, or none is found but several come close. Selection methods are required in such cases. Rational selection methods are the province of decision theory. However, the selection processes used by problem solvers are not directly related to decision theory. When several adequate procedures are found, they can be compared for cost and effort, but there is also likely to be a search for additional advantages of each procedure, advantages that are unrelated to the problem being solved. In addition, there may be individual differences in level of aspiration to contend with. An individual who lacks faith in his problem solving skills may be happy to accept a partial solution that would be refused by a second individual who expects to be able to achieve a solution that satisfies all of the solution criteria.

VII. CONCLUSION

We have presented a general theory that has focused on the problem reidentification process as the basis of problem solving. We have also presented a description of some properties that a complete theory of problem solving should have. These properties, of course, are analogous to solution criteria.

Since theory-building is a form of problem solving, we can use our theory of problem solving to describe out attempts to construct a theory. The problem was to develop a theory of problem solving. A solution is a theory that can explain the variety of problem solving behaviors people exhibit. In order to obtain such a solution (a satisfactory theory), we have begun by describing some of its features. As it becomes clear how the theory presented in this paper fails to describe the phenomena of problem solving, a better understanding of problem solving should develop. This is the way solutions are pursued.

REFERENCES

Ackermann, R. *An introduction to many-valued logics.* New York: Dover Publications, Inc., 1967.

Attneave, F. How do you know? *American Psychologist*, 1974, **29**, 493-499.

Bruner, J.S., & Potter, M.C. Interference in visual recognition. *Science*, 1964, **144**, 424-425.

Cohen, L.J. *The implications of induction.* London: Methuen, 1970.

Davis, G.A. *Psychology of problem solving: Theory and practice.* New York: Basic Books, 1973.

deGroot, A.D. Perception and memory versus thinking. In B. Kleinmuntz (Ed.), *Problem solving: Research, method, and theory.* New York: Wiley, 1966.

Dewey, J. *How we think.* Boston: D. C. Heath, 1910.

Dreyfus, H.L. *What computers can't do: A critique of artificial reason.* New York: Harper and Row, 1972.

Duncker, K. On problem solving. *Psychological Monographs*, 1945, **58** (5, Whole No. 270).

D'Zurilla, T.J., & Goldfried, M.R. Problem solving and behavior modification. *Journal of Abnormal Psychology*, 1971, **78**, 107-126.

Edwards, E. Conservatism in human information processing. In B. Kleinmuntz (Ed.), *Formal representation of human judgement.* New York: Wiley, 1968.

Gagné, R.M. Human problem solving: Internal and external events. In B. Kleinmuntz (Ed.), *Problem solving: Research, method, and theory.* New York: Wiley, 1966.

Goguen, J.A., Jr. Logic of inexact concepts. *Synthese*, 1968-9, **19**, 325-373.

Harré, R. *The principles of scientific thinking.* London: Macmillan, 1970.

Hesse, M. *Models and analogies in science.* Notre Dame: University of Notre Dame Press, 1966.

Inhelder, B., & Piaget, J. *The growth of logical thinking from childhood to adolescence; An essay on the construction of formal operational structures.* New York: Basic Books, 1958.

Kepner, C.H., & Tregoe, B.B. *The rational manager.* New York: McGraw Hill, 1965.

Klein, G.A. Effect of attentional demands on context utilization. *Journal of Educational Psychology*, 1976, **68**, 25-31.

Köhler, W. *The mentality of apes.* London: Routledge, 1927.

Machina, K. Vague predicates. *American Philosophic Quarterly*, 1972, **9**, 225-233.

Miller, G.A. The magical number seven, plus or minus two. *Psychological Review*, 1956, **63**, 81-97.

Miller, G.A., Galanter, E., & Pribram, K.H. *Plans and the structure of behavior.* New York: Holt, Rinehart and Winston, 1960.

Newell, A., & Simon, H.A. *Human problem solving.* New Jersey: Prentice-Hall, 1972.

Osborn, A.F. *Applied imagination.* New York: Scribner, 1953.

Pascual-Leone, J. A mathematical model for the transition rule in Piaget's developmental stages. *Acta Psychologica*, 1970, **32**, 301-345.

Peirce, C.S. *Collected papers.* Cambridge, MA: Harvard University Press, 1934-5.

Polya, G. *How to solve it.* Garden City, L.I.: Doubleday-Anchor, 1957.

Posner, M.I. Short term memory systems in human information processing. *Acta Psychologica*, 1967, **27**, 267-284.

Reed, S.K., Ernst, G.W., & Banerji, R. The role of analogy in transfer between similar problem states. *Cognitive Psychology*, 1974, **6**, 436-450.

Reitman, W.R. *Cognition and thought.* New York: Wiley, 1965.

Rescher, N. *Many-valued logics.* New York: McGraw-Hill, 1969.

Rumelhart, D.E., & Abrahamson, A. A model for analogical reasoning. *Cognitive Psychology*, 1973, **5**, 1-28.

Sanford, D. Borderline logic. *American Philosophical Quarterly*, 1975, **12**, 29-39.

Simon, H.A. How big is a chunk? *Science*, 1974, **183**, 482-488.

Tulving, E., & Thomson, D.M. Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, 1973, **80**, 352-373.

Wason, P.C. Reasoning about a rule. *Quarterly Journal of Experiemental Psychology*, 1968, **20**, 273-281.

Watkins, M. When is recall spectacularly higher than recognition? *Journal of Experimental Psychology*, 1974, **102**, 161-163.

Weitzenfeld, J. *Having a concept.* Meetings of the Society for the Philosophy of Psychology, Boston, 1974.

Wertheimer, M. *Productive thinking.* New York: Harper & Row, 1959.

Zadeh, L.A. Fuzzy sets. *Information and control*, 1965, **8**, No. 3.

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